ALE3D/EM Validation Experiments

Laura K. Tully
(925) 424-2235
tully2@llnl.gov

The configuration of high-performance magnetic flux compression generators and electromagnetic launchers depends on detailed knowledge of the effects generated by interacting electromagnetics, solid mechanics, and thermal phenomena. To provide this information, a coupled 3-D electro-thermal-mechanical (ETM) simulation code has been created that self-consistently solves equations of electromagnetics (primarily magnetostatics and diffusion), heat transfer (primarily conduction), and nonlinear mechanics (primarily elastic-plastic deformation and contact with friction).

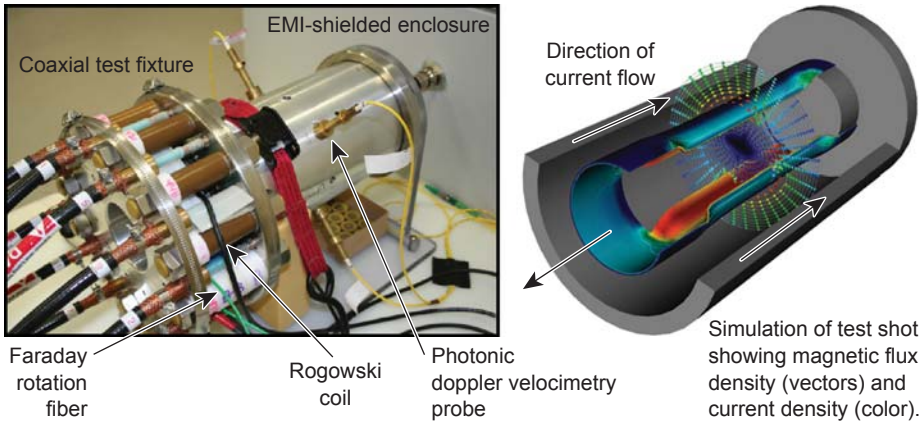

Figure 1. Coaxial validation experiment. The test stand uses a shorted transmission line and diverse diagnostics with results of a dynamic simulation from ALE3D/EM to provide a time history of the magnetic flux density, current density, and resulting mechanical deformation in the test fixture.

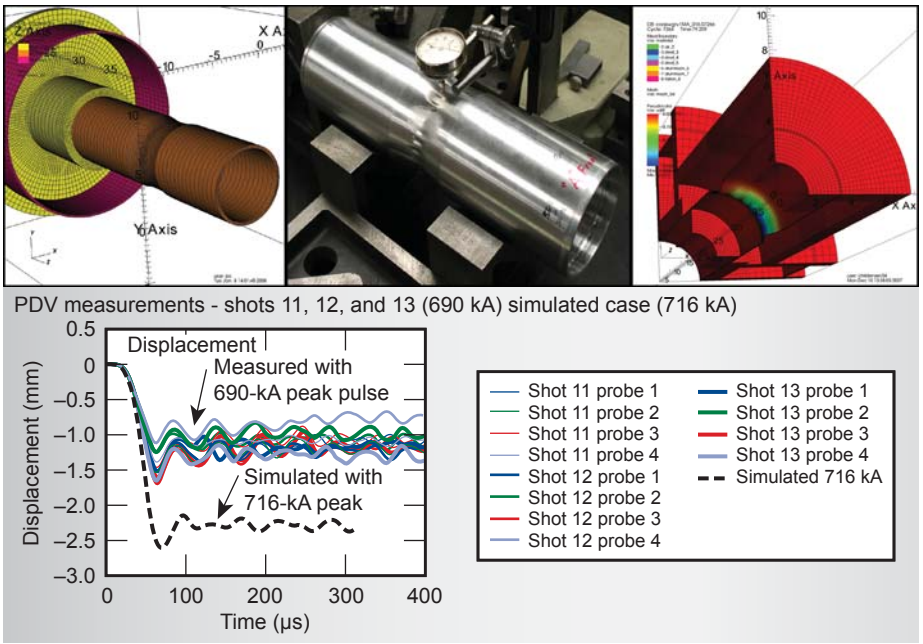

Figure 2. Early simulations and tests using the coaxial test fixture and a quadrant-symmetric simulation to model the formation of deformations and to initiate the study of instabilities that might be triggered by structural abnormalities.

ALE3D, a heavily used Arbitrary-Lagrangian-Eulerian hydrodynamics code with a large user community in the DOE complex, has recently been extended (ALE3D/EM) with an electromagnetics simulation capability to enable the simulation and optimization of ETM systems. In a similar vein, Diablo, a relatively new ASC-class parallel coupled multi-mechanics code built from LLNL-produced finite element (FEM) codes, has also been extended to include coupled EM effects.

We now have the foundation of a premier engineering tool for the simulation of the interacting electromagnetic, structural and thermal effects in high performance pulse power systems. Such systems are found in the overall power flow structures between flux compression generators and high-energy-density experiments as well as in electromagnetic launchers such as railguns. To round out this claim, we have started a validation campaign for the code.

Project Goals

The generation of high-quality data for validating simulation codes has been the challenging goal of this project. We chose to embark on a set of experiments that generate high-quality data for testing the accuracy of the modeling tools to be used for describing the details of the physical operation of the system. Concurrently, the experiments have been meant to provide the motivation and environment for the creation, testing, and qualification of experimental diagnostics.

A validation experiment was devised and a coaxial test fixture was used to provide high-quality experimental data from a controlled environment undergoing large magnetically induced deformations. These experimental data are particularly useful for the validation of coupling between **J** x **B** or Lorentz electromagnetic forces and structural momentum equations in ALE3D and Diablo.

The fixture permits injecting up to 1 MA current into a shorted coaxial transmission line from a 10-kV, 225-kJ capacitor bank. Such a current applies electromagnetic forces that crush the aluminum center conductor (Fig. 1). Our goal was to test the code against experiments using center conductor test cylinders of varying wall thicknesses, a nominal 6-in. working length, and 3-in. nominal diameter with a number of variations, including cylinders with slots or other imperfections, for the study of both 2-D and 3-D effects. This would enable validation in the presence of kink and buckling instabilities, and electrical contacts.

The fixture is such that the cylinders can be instrumented with strain gauges and thermocouples connected to signal conditioners and digitizers within an EMI-protected enclosure. The test fixture also allows for Photonic Doppler Velocimetry (PDV) measurements of the radial motion and displacements of the tube at four locations. Digital high-speed video is used to capture the rapid movement of the wall from a viewpoint within the center conductor of the structure. Accurate measurements of strain, temperature, displacement, and current have been recorded.

Relevance to LLNL Mission

These experiments provide a set of well-characterized data for the validation of engineering simulation codes for systems involving relevant, coupled electromagnetic, mechanics, and thermal effects. The validated codes are necessary for enabling LLNL to reliably create high performance systems and hardware. For example ALE3D/EM, when validated, promises to become the premier engineering tool for this purpose with widespread applications in explosive pulse power systems and electromagnetic launchers such as rail guns.

FY2008 Accomplishments and Results

FY2008 accomplishments have included the computer-supported creation of hardware for coaxial validation test apparatus, simulation of test shots in the coaxial test fixture, and the implementation and verification of advanced diagnostics for data acquisition. A successful experimental campaign included three "radial groove" axisymmetric shots (Fig. 2) and six "axial slots and radial groove" non-axisymmetric shots (Fig. 3). The high-quality data return was enhanced by Faraday Rotation and Rogowski Coil measurements for magnetic flux and current density; Photonic Doppler Velocimetry for localized structural displacement; and a high-speed video capture capability to record structural deformation on a more global scale at extended time.

Related Reference

Tully, L. K., D. A. Goerz, R. D. Speer, and T. J. Ferriera, "Modular High Current Test Facility at LLNL," *IEEE Inter. Power Modulator Conf.*, May 2008.

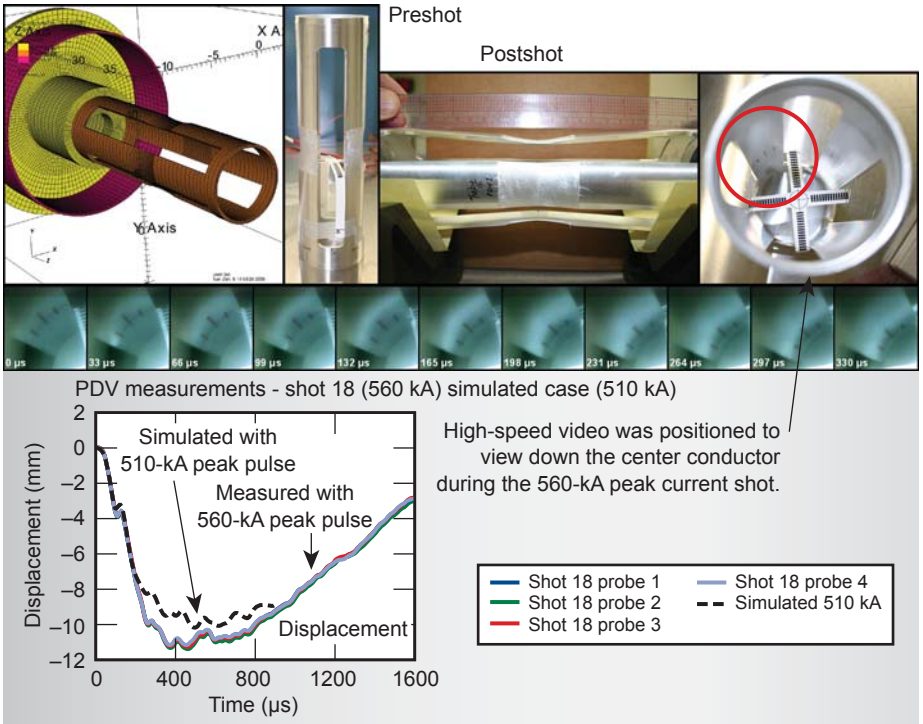

Figure 3. Sample results. A non-axisymmetric center conductor in the coaxial test fixture enables extension of the validation in the presence of instabilities in somewhat complicated structures. The full suite of diagnostics captures deformation of the center conductor with high-speed video capturing the dynamics of a large portion of the surface and the PDV system capturing, in high resolution, the displacement of a point on the surface.

FY2009 Proposed Work

In FY2009, we will investigate key areas especially pertinent to code validation. In particular, we will study the buckling and kinking instabilities that will challenge the full 3-D, high-spatial-resolution capability in ALE3D/EM. Using the high-speed video capability, we will be able to capture the formation of the modal buckling phenomenon with a microsecond-order frame-by-frame sequence over long time periods and therefore enable an extensive electromagnetic-structural-thermal code validation.